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Energy efficiency retrofitting services supply chains: A review of evolving demands from housing policy

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ABSTRACT

Attention regarding the energy saving potential of existing houses has been occurring within the UK for a number of decades, producing an evolving landscape of policy mechanisms. Experience shows that innovative schemes are required, implemented at a large scale, to reach carbon reduction targets. In an unprecedented move within the UK, private industry was enlisted with the task of delivering the most recent domestic energy efficiency policy; the Green Deal (GD). This policy required the energy efficiency retrofit services (EERS) sector to increase capacity and deliver efficiency improvements to the UK's existing housing stock, at scale. This review evaluates this Green Deal policy landscape in relation to the requirement of EERS sector expansion. Previous UK retrofit policies act as comparative exemplars, to assess how policy is progressing in promoting private enterprises. Key findings suggest EERS expansion is most successful if policies are designed more holistically; UK policies show strategies which focus on simply the property and not the occupants have their disadvantages. Therefore, a move away from marginal financial incentives, such as the Green Deal's loan structure, to a wider consideration of how policy tools interact with supply chains and end users, would enable increased impact.

1. Introduction

Domestic energy efficiency and the ability for tenants and home owners to live comfortably and affordably have been long standing foundation stones in the energy policy discourse. These factors have taken on enhanced importance as calls for heightened sustainability; economic activity and energy security have amplified. From a sustainability perspective, the built environment is estimated to use 37% of all energy consumed within the UK (2013) [1]. As the largest area of energy consumption, the Group of 8 (G8) countries have determined built environment energy efficiency improvements to not only be cost efficient but also substantial in having the potential to save 8.2 $GTCO_2$ per year, by 2030 [2]. This reduction in carbon emissions via an increase in energy efficiency is necessary to meet the UK's target of an 80% carbon reduction from 1990 levels by 2050 [1].

Many supporters retain that increasing domestic property energy efficiency via private sector delivery channels will meet sustainability and economic growth targets simultaneously [3]. To meet these targets, capacity expansion within the Energy Efficiency Retrofit Services (EERS) sector is required, involving the assurance that equipment, materials, production processes, investment, and the skills base are in place to absorb demand [4–6]. This challenge of increasing capacity is obviously a complex task; composed of numerous hurdles. To assist the advancement and growth of the EERS sector, governments intervene to accelerate rates of change via policy interventions. This research assesses the impact of UK policy mechanisms utilised during the recent past, to determine the ways in which barriers encumbering the EERS sector, to deliver retrofit at scale were brought down. This research does not claim to be comprehensive, but instead aims to be exploratory in highlighting specific effects from past policy mechanisms, and details key areas where the EERS sector benefitted or was hindered by the policy.

2. EERS sector activities

The EERS sector encompasses numerous activities from the design of refurbishment schemes, to the installation and ongoing maintenance of energy efficient equipment and materials. The stakeholders operating within the sector are wide ranging and include; contractors, designers, trades people and architects. In

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general there has been a deficiency of research focusing on the EERS sector specifically and its policy interaction, mainly due to the sector being previously identified as a sub-division of the general construction industry [7].

2.1. The EERS sector within an evolving policy landscape

In providing retrofit measures to increase carbon savings within the UK housing stock, the EERS sector is aiming to reduce the energy efficiency gap; the difference between potential carbon savings and savings which are actually realised [8]. Therefore, in designing policy to increase the level of energy efficiency upgrades, mechanisms are needed to effectively limit barriers to retrofit at scale and in turn the extent of the gap [9,10]. These barriers have been detailed extensively in existing literature and cover all areas from building heterogeneity, to business approach, to the behaviour of end users and the assessment of energy usage [11–15]. For this research the barriers of interest are those which are deemed by the literature to directly impact the supply chain, and inhibit EERS sector businesses from increasing capacity. In particular this research is focused on assessing the barriers which can inhibit retrofit processes prior to any end users being involved, thus, they are the barriers which are contained within supply chain inability, or the negative operational conditions within which businesses operate.

3. Policy schemes

This section provides an overview of the key UK energy policies to identify how expectations of the EERS sector have varied. These policies include the Green Deal (GD) and its sister policy the Energy Company Obligation (ECO) [16] and the precursor policies; the Carbon Emission Reduction Target (CERT) and Community Energy Saving Programme (CESP) [17]. Therefore, the mix of policy covers obligatory schemes utilising energy supplier funding and also schemes aimed at private home owners and housing associations. These schemes involved the allocation of differing amounts of financial input (Table 1), amounts which are important to consider when discussing policy impact. Throughout this research, these differences in cost will be referred to, to support findings in the level of effectiveness of each scheme.

Table 1 shows that due to the obligatory nature of ECO and CERT, and the fact that they operated at such a large scale, CO_2 savings per year were much higher in comparison to CESP which operated on a smaller scale, and the GD which did not have an obligatory aspect. The table also shows that both CERT and CESP achieved the most cost effective ways in which to save carbon, in comparison to ECO which placed a high requirement on energy companies to retrofit more vulnerable households, which required increased resources per retrofit, and the GD, which required increased finance to recruit loan applicants. These increases in requirements of scheme administration cause ECO to cost £61 per tonne CO_2 saved and £150 per tonne CO_2 saved for the GD.

3.1. Carbon emissions reduction target (CERT)

From 2008 to 2012, CERT was positioned as one of the UK's primary energy efficiency policy tools. CERT placed monetary obligations (Table 1) upon energy suppliers to reduce customer carbon emissions via retrofit measures. 60% of savings had to be achieved via insulation measures, and the remaining 40% of carbon savings needed to focus on energy savings within priority groups (low income, elderly households) [17]. CERT development grew from a technical base, emphasizing the take up of carbon saving measures. This produced a policy which was focused and achievable, with a high degree of stakeholder consultation, particularly with suppliers [19]. In addition to the policy focus, transparency and target setting offered policy clarity, and contributed to success in delivering high volumes of energy saving measures [20].

3.2. Community energy saving programme (CESP)

CESP was a scheme funded via energy company obligations, aimed at providing funding to community groups, housing associations and local authorities to improve property energy efficiency. CESP emphasised a whole house approach, treating properties street by street [21]. During the operational periods of 2009–2012, the scheme, alongside CERT, financed almost 100 community initiatives, resulting in 90,000 individual property retrofits. The impact of the scheme meant that in a post retrofit assessment, 75% of participant's agreed that their property was warmer and took less time and energy to heat to comfortable levels [22]. The CESP delivery model focused on creating partnerships and schemes which were locally specific, offering a method of increasing the rate of localised energy savings particularly within deprived areas. This local emphasis meant that the delivery model focused primarily on the economies of scale which could be generated on large social housing estates for instance [20].

3.3. Green Deal (GD)

Operational from late 2012/early 2013 to July 2015, the GD permitted bill payers to retrofit their properties with energy saving measures, without the need for any upfront payments [16,23,24], as loans were secured against the property. This meant homeowners and tenants could save energy without the need to take on personal debt [16] . Repayments for the retrofit upgrades were generated via on bill payments post installation [25]. The GD relied upon 'the Golden Rule' to ensure that the value of any energy saving generated by the improvements, was no less than the repayments for the measures [26]. The delivery, management and financing of the GD was placed in the hands of the private sector. A consortium made up of banks, businesses, local authorities and investors took on the responsibility of finance provision [3]. Plus, during the early stages of the policy, the Government offered cash back incentives to early adopters, by way of accelerating initial demand [16, 24] (Table 1).

Table 1
Policy cost comparison.

Policy	Timeframe	Annual expenditure (£bn)	CO_2 savings (lifetime) per year (Mt)	Cost per tonne CO_2 saved (£)
GD	2013–2015	0.24	0.4	150
ECO	2012–present	1.00	10.47	61
CERT	2008–2013	0.79	26.24	34
CESP	2009–2013	0.22	1.28	34

(Figures originating within DECC National Audit Office, Green Deal and Energy Company Obligation Report. April 2016 [18]).

3.4. Energy company obligation (ECO)

ECO operated alongside the GD in aiming to tackle carbon saving and fuel poverty simultaneously. ECO fitted in with the GD by offering measures that do not meet the Golden Rule assessment; positioning ECO to deliver measures which are less cost effective [27]. Additionally, ECO's design is structured to provide high cost measures to low income households, or those in fuel poverty [26]. The two policies were linked via the method of delivery as the private businesses providing the services had the potential to be the same organisations, with the ability to bundle additional measures on top of an ECO funded package (Table 1) and process this addition as a GD energy efficiency improvement [24]. Providers gained 'jobs' by bidding on brokerage auctions fortnightly to win 'lots' of ECO retrofit projects, sold by the energy companies [28,29].

The initial ECO model was unprecedented within UK policy design, and therefore contained some initial issues. Firstly, as the scheme prioritised hard to treat properties with solid wall insulation, and cavity wall measures, there was a knock on effect in the relative restrictions in other areas of the market [30] . Secondly, in focussing on high cost measures, which inherently require greater obligation funding (Table 1), ECO applied a lot of pressure on businesses supplying solid wall insulation and cavity wall insulation to grow in capacity at a fast pace [31]. Thirdly, research indicated that the proposed impact of ECO was too limited. By 2023, ECO was anticipated to remove 125,000–150,000 households from fuel poverty, a number which was 20–40 times too small to tackle the problem [32]. Meaning that ECO could have actually been in place, while there was a 29% increase in fuel poverty [33].

3.5. Transition to GD and ECO, impacts upon the EERS sector

Due to the fact the GD was designed to be financed, managed and delivered by the private sector, with a removal of significant public funding (Table 1) the development of the supply chain was key [5]. The estimations within the GD's impact assessment places the EERS sector in a difficult position, as the expectation was for a significant growth in capacity, knowledge and business capabilities, within a short period. With this level of required capacity increase in mind, details of how present and past policies have assisted businesses in overcoming barriers, follows.

4. Methodology

4.1. Policy learning via comparative analysis

The concept of policy making is one that has been stated to be viewed and understood as a learning process [34], for official employed policy makers or by social actors within general society. This idea based learning is opposed to conflict based progress, whereby policy changes are brought about by pressure from society, regarding distaste with a specific policy instrument or paradigm. With idea based learning or policy learning however, there is the option to look deeper at present policy and produce via comparison, a more informed environment [35]. Furthermore the process of policy learning to create ideas offers the opportunity to learn not just about differing policy models, but also about differing structures for decision making, processes, aims and innovations [36]. From this therefore it can be seen that policy learning not only serves the purpose of identifying process and policy innovations, but also provides a method of determining how the lessons resultant from the learning process can be brought into action [37].

Utilising a comparative analysis framework provides an insight into differing ways of working that are concealed by the differing organisational, cultural and societal structures within which they operate [38]. Therefore, a comparative assessment between retrofit policy mechanisms, based on Rose [32,38] and also Murphy et al., [29] who utilise a comparison of retrofit policies across differing countries, generates a base of evidence to develop ideas from which policy progress can result. This approach advocated by Rose, requires the isolation of differing elements of a policy, but without the intricate description of the ways in which the policy mechanisms operate.

From this therefore, within this research the specific policies of the GD, ECO, CERT and CESP have been selected, which are considered to offer an abundant evidence base, and are chosen due to their significant policy documentation and shared geographic areas of impact and policy aims, all factors considered key for comparison to Rose [32]. Sources utilised for the assessment of the policies against the barriers outlined above, include peer-reviewed academic papers, plus government and industry reports [16,19,22,20,39].

4.2. Assessment criteria

EERS sector business strategy and formation to maximise retrofit scale potential, is the focus of this research. Therefore the key barriers under assessment are those which detail, business operation strategies and supply chain formation. The specific selection of barriers for assessment against the four policies has taken place via a literature review, further details of which and a breakdown of differing barriers under consideration is available in Gooding and Gul [40] with additional details in Britnell and Dixon [41]; Decanio [11]; Gooding and Gul [42]; Lowery et al. [43] and Mundaca [14]. Via this review the following shortlist (Table 2) has been produced, whereby all the factors have the power to limit the amount of the effective formation and performance of EERS sector businesses. The table details these barriers and looks at the impacts of the barriers and requirements to lessen the barriers negative impacts.

Utilising existing literature and policy documents, the differing policies are now assessed in terms of whether these barriers (Table 2) are removed, remain in place, or are partially tackled, a rating relating to these levels is then applied to the policies. The scores for the policies are informed via literature and policy documents, and ranks policies lowest if there is no comment on specific barrier removal, secondly if the barrier is commented on in documentation, thirdly if the policy explicitly specifies overtly methods to remove barriers, and fourthly if the policy explicitly specifies methods to remove barriers and has created related positive results. With these scorings, this method seeks to compare policies in an exploratory way and detect innovative policy thinking, where learning can take place.

5. Level of policy success in aiding the growth of the EERS sector

5.1. Business relationships with end users

The barrier of a lack of awareness or tailored information detailing domestic energy efficiency, due to ineffective business/end user relationships, can lead to limited uptake of policy measures and a poor business/client relationship. This can then produce hindrances to the EERS sector in gaining customers and issuing successful marketing campaigns and business development schemes. Without information designed for specific groups, imperfect information will result, with end users misinformed [48], and motivation to take up retrofit services remaining low. Therefore if an EERS sector business is to be successful in its pathway to gaining business, information issued to the client needs to be

Table 2
Barriers limiting EERS sector growth.

Business relationships with end users	The need for correct business formation to be able to form a successful relationship with the end user. Without correct formation this barrier impacts the level of business available for completion due to ineffective information being issued to the customer and resultant awareness being low. Research suggests that households in the process of undertaking retrofit work had a greater awareness of retrofit benefits, including money saving and thermal comfort, when compared to those who are not planning retrofit work [44].
Business hidden costs or transaction costs	DeCanio [11], states that hidden costs, or transaction costs, are key factors hampering the growth of businesses. Hidden costs occur in various forms, from the cost of sourcing information, setting up the supply chain, to gaining business contracts [45]. These processes detract from the level of profit achievable and therefore limit investment channels. For a capacity increase in the EERS sector and for new business enterprises to establish there is a need for policy to generate financial conditions limiting the risk to investors, and providing arenas to encourage innovation developments in products and processes [45].
Business organisational barriers	For new or expanding EERS sector businesses, there is the need to identify niches and predict downstream capacity and potential future competition, along with developing innovations, problem solving and an awareness of respective roles within an integrated delivery team. Without policy mechanisms to offer this organisational market structure, it will be difficult to create a competitive sector compared to existing more traditional construction and refurbishment markets.
Barriers limiting the opportunity for innovation	Low carbon housing retrofit is a singular solution which can address wider problems of fuel poverty, climate change, and energy security [46]. Therefore, understanding how retrofit could operate with differing systems and projects, may lead to innovation and streamlining, enhancing the viability of retrofit opportunities [47]. Generating conditions which foster increased understanding of the need for innovative products and processes may lead to high delivery efficiency and profitability.
Business inability to remove inertia and entrenched routines	Entrenched routines and habits cause issues of energy inefficiency to be simply ignored [15]. Without the provision of mechanisms and incentive from EERS sector businesses to remove inertia, even the most appealing policy instruments may be ignored.

sufficient in terms of projected energy performance and related savings from installed measures, transparent in terms of agreements between business and client, and also free, to ensure that all types of households have equal access to the possibility of retrofit works [49]. Additionally, end users may be limited in their enthusiasm for energy efficiency information and therefore may only take in certain media formats detailing housing retrofit, and not search out differing data sources [15,50]. This means that for this barrier to be overcome, policy needs to work with supply chain actors (section 2.1) to ensure that information is well detailed, highly available, and consistent.

The GD and ECO did go some way to enhance demand and generate increased awareness, via building good quality relationships with end users. Within the GD policy documentation, the intention was to be focused and structured around the needs of the consumer and businesses [51]. The reasoning for this is to guarantee a widespread uptake of retrofit measures, with the corresponding supply chain to meet demand. Policy documentation stated that all GD providers and assessors are accredited and business practitioners act as a first port of call for end users; '*we anticipate that the involvement of a diverse market of local and national firms of all sizes will find interested customers more effectively than any top-down Government scheme* [16].'

In theory this model has its merit as the anticipation was that a customer carrying out standard construction work will have the opportunity to discuss with trades-people on site the option to install accompanying energy efficiency improvements. This reliance upon commercial actors also means that the policy was dependent upon private enterprises to provide training and boost the skills base [16,52]. Both factors are designed to positively influence domestic energy efficiency increases, due to the potential to boost the penetration of the issue within mainstream construction activity.

From this review, evidence suggests that government provision and support to aid awareness generation with the public, was limited. The assistance which was government provided came from a small fund of money to provide GD cash back finance to early adopters [16,51] (Table 1). This fund does indicate that policy had the intention of driving awareness up, however, for the period November 2012 to April 2014, the GD Household Tracker survey only showed a 10% increase in the number of respondents who were familiar with the GD [53, p15]. The same period also saw a 4% drop in the general awareness of energy saving measures. This is evidently concerning for the overall aim of private industry providing a diverse market, which sources customers [53], and also displays the potential requirement for additional support from government.

More positively, the Tracker Survey does state that from November 2012 to April 2014 the awareness of the GD quality mark did increase from 12% to 23%, showing that awareness of the role of private businesses and the importance of accredited trades people grew [53]. This means that overall; the performance of policy in promoting business ability to generate successful relationships with end users, via issuing quality information was minimal, with changes in policy required to be more supportive of the supply chain [5]. Furthermore, there is a clear indication that the limited financial input within the GD from government has caused limited impacts in uptake and awareness increases. This reduction of financial assistance within the GD is unprecedented within this policy arena (Table 1), with the GD being relatively unsupported in comparison to the other policies under consideration [22 p34,18].

In contrast CERT utilising an increased level of government financial assistance operated a raft of differing mechanisms [18], both driven by private industry and public agencies, to increase engagement and information dissemination. Within CERT policy documentation, interaction with the public, information provision, and lead generation were intended to be carried out by a combination of; national advertising by large energy suppliers, Energy Saving Trust advertising supplemented by a dedicated telephone line, marketing by retail companies including DIY stores, and door-knocking by installers [19]. Unlike the GD therefore, the emphasis on the EERS sector to carry out all lead generation was absent, meaning the level of policy/business support and cooperation was increased, via boosted financial resources [18]. This enabled a higher level of barrier removal as an environment was created where, with good business/client care 35–50% of referrals could be converted to full retrofit installation, and with sustained local marketing and financial support up to 60–70% of customers who were directly engaged, converted to installation [19, p26]. This means that the energy company obligatory target was exceeded by 3% for the operational period (April 08-December 12), equating to a saving of 75 Mt CO_2 [54, p4].

CESP on the other hand, with the limited areas within which it operated (due to being confined to work with communities below

certain indices of deprivation), caused limitations to the amount of quality business/end user relationship building which could take place. Due to the fact suppliers required a certain number of properties to meet requirements, in the main social housing providers were used to gain properties, not end users. Although this produced economies of scale for EERS sector businesses and an increase in social housing standards, end user behaviour and information provision was not necessarily being addressed [22]. This lack of interaction with end users from the commencement of a project meant that delivery partners required good tenant liaison skills, along with a pilot home to use as a show home to reassure end users [22]. The fact that interaction with end users was not carried out during the entire project schedule also meant that within the *Evaluation of the Community Energy Saving Programme* only 51% of respondents stated that they had received some sort of instruction as to how to run a home efficiently [22, p17]. This percentage meant that end users felt in general that there was scope to improve this advice, as with a higher level of education received, the more significantly respondents felt they would have benefitted, therefore the need for businesses to increase their methods of communicating with end users was still required. Furthermore, the survey found that 64% of participants found they were unsure their heating expenses had reduced post retrofit, enforcing the requirement that an emphasis is needed on education [22, p18] . Overall therefore, due to the limited business interaction with members of the public, quality relationship building was limited, hindering the amount of knowledge transfer and thus possible energy savings into the future.

5.2. Business hidden costs or transaction costs

Hidden or transaction costs (TCs) are costs related to operational procedures and therefore can hamper the growth of businesses [11]. These procedures detract from the level of profit achievable and therefore limit investment channels. For retrofit activities, TCs result from the processes involved in project preparation, finance searching, construction supply chain formation and negotiation, plus ongoing post project monitoring [45]. Combined, these costs deter investment in energy efficiency measures, as TCs can form 30% of the final installed cost of cavity wall insulation, and 10% of lighting improvements [14]. Even with percentage estimates such as these however, the level of uncertainty around TCs is still high. This lack of accuracy is due to a deficiency of data regarding technological performance, data source reliability and the unproven nature of monitoring and cost quantification. The resultant effect of TCs is that they make emergent processes and technologies prohibitively more expensive than more established alternatives. For EERS sector businesses, retrofit projects can produce significant hidden costs in comparison to the business opportunity scale [55, 56] . Meaning policy priorities should support effective market growth and generate financial conditions limiting investor risk and therefore EERS sector business growth.

In comparison to CERT or CESP which focused on low hanging fruit to meet carbon reduction targets [29], under the GD, businesses were initially required to provide higher cost solutions [16]. This heightened complexity of delivery meant that the focus on labour intensive mechanisms such as cavity wall insulation (CWI) and solid wall insulation (SWI) increased. In focusing on these technologies, the GD estimated an increase in the number of installers, and thus a knock-on effect on the wider supply chain [32]. This change of industry formation produced costs to business; to create GD compliant, profitable and effective business structures quickly. To reach the UK's carbon reduction targets, 12,000 properties needed to be retrofitted per week from 2014 [57], however, past statistics of the cavity wall insulation (CWI) industry suggests that this is out of reach in the short term. With the highly publically financed CERT scheme pushing the industry, installations grew to 550,000 in 2005 [39]. This growth in scale is positive, but if the CWI industry is representative of the whole EERS sector, reaching 12,000 properties per week seems ambitious without significant policy assistance and financial aid (Table 1).

Nevertheless, in endeavouring to minimise hidden costs affecting the EERS sector, the GD did create, via accreditation and quality marks, a risk management framework [58]. This aimed to strike a balance between protecting customers with ‘red tape’ and also limiting the commercial administrative load [59]. However, under the GD, an installer or provider still had to finance the standard on-going cost of operating a business, plus the initial cost of £16 and an annual cost of £8 per GD package to cover the costs of the GD finance administration, in addition to the cost of marketing and sale activities per retrofit [60, p70]. Furthermore, within the supply chain there is the cost of accreditation, assessment and product certification; all these overheads exacerbate the issue of TCs and hidden costs.

In contrast, ECO's brokerage platform offers installers and providers a method of alleviating marketing costs and minimising administration costs. The certainty of supply via ECO creates favourable conditions for businesses to invest and generate increased capacity, creating economies of scale, decreasing the impact of transaction costs. However, although in design the system should provide certainty via the brokerage, due to changes within the policy, activity resultant from the auction mechanism has been minimal. In December 2013, one auction for instance produced no sales. This may have been due to the same month being the time at which energy suppliers had their timings to meet their obligation doubled [61], meaning for supply chain businesses, insecurity levels increased. This long term uncertainty shows that businesses cannot operate unless there are guaranteed conditions and therefore predictable TCs.

CERT, throughout its operational period produced an environment of flexibility and stability, which enabled the establishment of highly cost-effective routes of delivery to satisfy the requirements from the Office of Gas and Electricity Markets (OFGEM) and legislation. The scheme created in effect a commodity market by assigning a price per tonne of carbon saving [19]. The market encouraged the entry of new enterprises, which in turn reduced over time the hidden and transaction costs impacting businesses. In DECC's 2011 evaluation of CERT, feedback from practitioners enforced this point stating that CERT had been the most cost effective way of providing carbon savings, when compared to CESP, in terms of the types of measures installed and related administration costs [19].

Nonetheless, CERT did also produce negative impacts upon the EERS sector delivery network. Firstly, the factor that CERT encouraged competition between suppliers and stakeholders, due to the tight timescales and price margins at work, a lack of transparency resulted [20]. This absence of information sharing drives transaction costs up as knowledge distribution is absent. Secondly, due to reliance upon the supplier obligation bringing installer's work, difficulties can arise in assigning resources and managing a business when peaks and troughs are encountered. Thirdly, the fact that the market for retrofit under CERT caused a distortion in market value, due to subsidisation meant that some suppliers faced more difficulty than others in gaining finance. Fourthly, due to the level of obligation for the suppliers of the retrofit schemes, and the heightened level of uncertainty regarding what retrofit measures were actually included under CERT, some suppliers ended up providing work for free, to ensure take up and to remove financial penalty risks. Furthermore, as the policy progressed, additional obligation groups, such as the Priority and Super Priority Groups

meant that achieving representativeness of the groups, required significant resources [54].

CESP worked to minimise transaction costs by working with existing practices, this occurred in multiple ways; present relationships with housing associations and providers were built upon. To limit costs associated with setting up new working procedures, existing housing data was utilised to enable a streamlined method of assessing a project status, and experienced actors from both housing associations and EERS sector businesses were utilised to bring knowledge and drive to a project. Plus, CESP was utilised on existing projects thereby building on previous work to bring carbon savings [22]. All of these measures reduced the administration load and hidden cost impact on EERS sector businesses associated with growing or setting up an operation.

Nevertheless CESP, in practice did generate significant issues for practitioners. Initially due to a lack of awareness within local authorities and housing associations of CESP and its impacts upon their activities; the level of guidance and support required was higher than anticipated at the policy design stages. Once housing associations had been brought on board with the scheme, the administration and management of project funding caused further issues. These problems included the percentage of funding required by energy companies versus that derived from the property owner (housing association, council), and also who was liable to finance additional works and contingency costs [22]. In the assessment for the suitability of a project, additional hidden costs were encountered including those of navigating the large variances in the quality of housing stock information. Lastly, the scheme also fostered principal agent relationships whereby delivery partners perceived a lack of transparency in the practices of the energy company and a lack of control from the view of the local authority or housing association [22].

5.3. Organisational barriers

With many EERS sector businesses being classed as micro businesses [7], the need to identify niches and predict downstream capacity and potential future competition is important. From this therefore, it can be appreciated that to encourage growth and retrofit at scale, EERS sector businesses need to adopt organisational cultures that provide opportunities to innovate, and implement extensively researched business plans [62].

For the GD and ECO the required organisational cultures needed to provide measures which created an EERS sector organised in such a way that growth and profitability were generated. The policy's practitioner accreditation did aid EERS sector growth to an extent, meaning issues of a lack of expertise or knowledge were reduced. Although the accreditation GD stakeholders received did not extend the level of accreditation within industry to a large extent, it did consolidate requirements, which increases the level of end user confidence [16]. EPCs for instance are an area of regulation which the GD utilised, along with already existing installer accreditation body data, and requirements from industry for minimum product performance. Accredited advisors and installers were the only businesses and operatives permitted to trade under the scheme, creating a limited force on competition. DECC financed and put in place a supervisory body to alleviate this issue. From this standpoint, the GD performed in a manner which did assist the growth of an organised, effective supply chain, utilising already present factors to minimise negative impacts on the EERS sector.

The affectivity of the GD and ECO accreditation scheme is evident, when considering the continuing growth of accredited organisations. Up until August 2014, the number of individual assessors had steadily grown to 4,219, the number of providers increasing to 156, and the number of installers rising continuously to 2735 [63]. This increase in businesses provided a continuing growth in the variety of services offered and in turn the level of inter-business competition. Additionally, for EERS sector businesses involved in product innovation, new products were subject to higher accreditation costs to enable their entry into the GD's roster of permitted products. Although these costs limited competition within the market, the overall effect was one of advancement due to the increasing size of the market and product roster compared to previous schemes [60]. However, these measures did not produce the desired volume of results. In fact from the GD's commencement in January 2013 to August 2015, just over 12,000 properties were retrofitted and completed [63]. This lack of success may be due to the fact that in general the GD via the Golden Rule prescribed that any savings generated by measures must be larger than the finance injected into a project. This in turn meant that in reality only low cost measures qualified, measures which in the past were delivered by obligations such as CERT. The difference between the delivery mechanisms is that with an obligation the outcomes of a scheme are certain, whereas through the GD the level of delivery was left entirely up to the EERS sector, meaning greater uncertainty. Plus, in many cases the types of low cost measures were unsuited to a finance loan, as their capital costs were relatively low. From this therefore the GD needed to optimise the types of measures which the finance package catered for. Furthermore, the higher cost technologies could also be considered as sub optimal due to the unlikelihood that they would fit into the Golden Rule's calculations. As it stands therefore, the GD produced a framework of measures which were not enticing to end users and were not easy to sell.

ECO, via the obligation it places upon energy companies, can guarantee a certain volume of properties to the EERS sector. This means that investment in business resources and training schemes causing growth can occur in an environment where financial returns for business are more assured [64]. In comparison to the 12,000 properties retrofitted under the GD, over the same period, ECO delivered over 1.5 million measures [63].

CERT on the other hand encouraged the removal of organisational barriers via the coupling of differing types of organisations, including installers, merchants and consumer groups. These partnerships resulted in the co-development of a supply chain characterised by feedback and continuing progress [20]. Moreover, cooperative processes, act as promotional methods to encourage uptake, and without commercial barriers, new methods of working were created.

Evidential cases;

- British Gas and Sony partnership to increase household electronics energy efficiency.
- EDF Energy with Ice Energy partnership to deliver heat pumps.
- Lemnis and EDF partnership to delivery low energy light bulbs.
- 24 London boroughs working with housing partners to retrofit 50,000 homes.
- Npower, Rockwool and Build Centre partnership to offer reduced insulation purchase costs for DIY customers [20].

The diversity and innovation within these types of partnerships is evidently a positive force in finding new ways to meet the UK's carbon reduction targets. The success of these schemes was influenced by an already present strong supply chain, offering an early indication as to the confidence of the delivery method [19]. However, these successes within the organisation of businesses were undermined by the way in which CERT created difficulties, via the changing of measures covered by the policy. This fostered a lack of trust, with investment by businesses reduced to limit risk [19], and delays incurred to EERS sector expansion.

In contrast, creating effective and profitable organisation structures under CESP was more challenging due to obligated parties having to gain approvals for retrofit work from local authorities. This localised governance of the scheme did not lend itself to fostering innovative operations as resources were limited. Furthermore, as CESP projects can only be completed in clearly defined and constricted areas, the opportunity to streamline organisational structures was limited.

5.4. Barriers limiting the opportunity for innovation

The extremely heterogeneous nature of the existing housing stock creates a major barrier to EERS sector companies; firstly a high level of expertise is needed to tailor solutions to a wide range of property types, secondly, economies of scale are difficult to generate as each property requires differing measures, and thirdly, high levels of investment are needed to research and develop solutions which can cater to differing property types [13].

In attempting to produce a universal 'Golden Rule', the GD specified particular technologies and measures which were deemed financially suitable to certain properties. This provided a more streamlined method of assessment and property categorisation. Furthermore, the GD had the advantage of being able to adapt to an evolving market. This dynamism meant that if modifications occurred to existing technologies or more cost effective solutions arose, or indeed if higher energy costs brought more expensive mechanisms under the Golden Rule, the roster of measures could evolve [60]. This drive for products to become more economical, to enable access to the GD system, meant the policy had the effect of incentivising industry. This motivation had the potential to produce the development of lower cost technologies or provide cheaper finance, permitting the opportunity to apply a product to the mass market. This is an advantage over the CERT and CESP mechanisms which due to higher level public and Energy Company funded subsidisation (Table 1), brought complacency and retention of product costs [20]. However, for this GD design to work successfully, it must have operated a process whereby new innovations could be swiftly but thoroughly assessed and tested, to promptly offer as wide a range of products as possible to ensure that the viable roster of products under the Golden Rule was maximising possible carbon savings [60]. Furthermore, due to the need to develop as near to a whole house approach as possible, finance tools were required to work outside the standard GD finance structure, to enable more costly measures to become viable to end users. During the initial phases of the GD a £10 million project was launched to stimulate the development of innovative products, these technologies were encouraged to emerge from a consortia of supply chain members, including building owners and material suppliers [65]. This analysis shows that the need for innovation is addressed in the GD policy documentation; however, due to low numbers of retrofit projects under the GD, associated results are lacking. An additional factor exacerbating the factor that policies can inhibit routes to innovate and evolve is due to the limited ability of assessment procedures, making accurate calculations of technology or material performance once in situ difficult. From this, any calculation made by an assessment procedure such as the Standard Assessment Procedure (SAP) as with the GD, may be subject to discrepancies [3]. These differences between the predicted and actual savings can be due to factors such as thermal bridges, insulation gaps and increased energy usage post refurbishment due to the rebound effect [66,67,71,68], exacerbating the energy efficiency gap [8]. Testing of products assumes ideal installation and standard conditions; therefore to achieve predicted savings within a live project is very difficult [69]. Plus with the rebound effect or take-back effect whereby the impact of lower energy costs post retrofit alters the end user behaviour. In the case of inefficient properties they are in the main, under-heated to provide savings to the occupants [70]; therefore retrofitting a property provides the tenants or homeowners with an attitude to take-back the energy they have previously refrained from using, due to financial restraints [71]. This factor of end user behaviour is not to be underestimated as it is calculated that behaviour can have the same impact on a property as energy efficiency technology and materials [72]. In the case of the GD these human factors were outside the capabilities of SAP, and therefore retrofit measure implementation may be missed due to inaccurate calculations [73], or loans supplied via the GD could have been inaccurate [2] due to the Golden Rule calculations being void.

ECO, due to its emphasis on partnering and bringing together construction consortiums is achieving significant investment via obligation. Due to the fact obligated parties such as British Gas, E.ON and EDF [74] are investing finance to achieve retrofit at scale, EERS sector businesses need to also produce methods and innovations which can reduce the per unit cost of retrofit to enhance the economic viability of the industry. This volume of property numbers under ECO is evident in the fact that during the period January 2013 to July 2015, over 1.5 million measures were retrofitted [63]. Furthermore, as ECO has a focus on tackling the issues of hard to treat properties, process and product innovation is encouraged, to attempt to deal with property type variances. However, there is also the impact of ECO focusing on higher cost measures meaning that low cost products, which policy anticipates to be used under the GD, are not benefitting from the volume of projects stated above. Similarly to the GD, ECO does have provisions to encourage investment and innovation, however in the limited areas where ECO is focused; addressing the heterogeneity of the entire UK housing stock is not taking place.

CERT addressed property variances by promoting collaborative working between differing types of businesses and groups, encouraging innovation. This approach produced pioneering methods specifically designed for a certain house or development type [20]. CESP achieved this, but on a smaller scale, due to the lower volume of properties, and due to a reduced number of property and occupant types. In providing free or heavily subsidised measures, CERT and CESP did however to an extent generate a false market for both suppliers and end users. Providers became overly reliant on large sums of subsidisation money (Table 1) and due to the consumer gaining the retrofit for free, or at a heavily subsidised rate; the incentive to innovate was reduced. This effect was a driving factor within the design of the subsequent GD, which focused on private businesses undertaking policy implementation, reducing the burden on public funds.

5.5. Business inability to remove inertia and entrenched routines

Entrenched routines and habits may also limit retrofit levels, as people may not be willing to disrupt their daily lives or surroundings [75]. These routines are difficult to break and may cause issues of energy inefficiency to be simply avoided or ignored [15], limiting the supply of properties for retrofit. Furthermore, bounded rationality can cause a reduction in the number of households making rational economic decisions to have their property retrofitted. This can cause energy efficiency measures to not be undertaken, even though improvements may be economically profitable and rational [12]. This can be due to energy efficiency decisions requiring complex problem solving to achieve optimisation, or the fact that multiple actors within a household inhibit a rational decision to be made [15].

Although, marketing under-investment from public sources limits public awareness, in concept the GD did remove inertia and

irrational behaviour influences, via the design of the seamless delivery programme within which accredited EERS sector businesses must have complied. Both the GD and the sister policy the Energy Company Obligation (ECO) placed the responsibility of delivery on energy companies and GD providers [27], therefore limiting end user involvement, and in turn the amount of awareness and knowledge required. Nevertheless, in solely focusing on fabric improvements the GD and ECO could have missed an opportunity to address the factor of behaviour in energy consumption [3], which could leave the impacts of the rebound effect remaining [76].

What is more, the carrot that was provided via the scheme (financing of measures) did not completely remove the financial barrier to energy efficiency upgrades. There is concern that due to limited government support for the scheme (Table 1), the interest rates did not make the privately funded retrofit loans very attractive to possible clients [77]. This high price for the loan was exacerbated by private businesses being reluctant to lend money without the government underwriting the loan. Therefore not only are the benefits uncertain due to the inaccuracies discussed previously around the SAP assessment procedure, but in addition, the loan finance could have been sourced in a much more cost effective manner, in the form of a mortgage for instance. In addition to this unattractive finance package, the GD also failed to address the ways in which end user behaviour looks to minimise the level of disruption. In the case of a loan funded retrofit, many home owners and tenants simply see the exercise as a large amount of upheaval from existing routines for only a potential marginal economic return. From this standpoint therefore, in many ways the GD could have been seen to be an irrational choice for end users, and also a tough sale for EERS sector businesses, even though the scheme was designed to appeal to rational economic thinking [78].

In the case of CERT and CESP, to ensure suppliers met their quota, and to avoid subsequent financial penalties, retrofit measures were offered at a significantly subsidised rate to promote uptake [20]. This in turn removed the financial barrier encouraging inertia. However, in providing free or highly subsidised retrofit measures, there is the effect that end users do not appreciate the full value of the property improvements. This hinders the possibility of behavioural changes, meaning the full potential savings of retrofit works may go unrealised. In addition, for CERT, the factor that ad hoc changes were made to the availability of differing measures under the scheme exacerbated the effect of bounded rationality and decision complexity for end users [19]. Therefore with a wider range of measures, EERS sector engagement with customers may have been more effective.

Due to the restricted geographical areas in which CESP operated, engagement and inertia removal was selective and was restricted to a few specific postcodes with defined socio-demographic parameters. Nevertheless, due to energy efficiency providers primarily engaging with social housing organisations, the need to remove end user inertia and bounded rationality was not present [22]. This evidently streamlined the EERS sector's delivery in those areas, and ensured the supply of properties was present, even if there was a missed opportunity to address occupant behaviours.

6. Discussion

The overall outcome of the research is represented by Fig. 1; this graph serves as a central point for this research and represents the overall contribution of the policy assessment and policy learning. To generate a relative ranking of policy ability to remove barriers, the differing mechanisms discussed here are graded from 1 to 4, dependant of the extent to which barriers halting retrofit at scale are dealt with. These grades are defined as follows:

1. Barrier un-tackled
2. Weak (barrier partly addressed)
3. Moderate (tackling of barrier explicit in policy documentation, but with limited associated results)
4. Strong (barrier tackled with associated results)

The five areas where policy needs to be effective to enable retrofit sector growth are given below as points on the radar graph (Fig. 1). Each barrier is numbered (5.1, 5.2 etc.) corresponding to Section 5 of this paper.

Based on the review of policies undertaken in Section 5, one may conclude that the public knowledge of retrofit and its benefits can be increased with tailored forms of information provision and a focus on fostering transparent, informative business/client relationships. In the case of the GD and ECO, policy design highlights the requirement of tailored marketing, and stipulates that via the use of many differing types of EERS sector business in policy delivery, awareness generation across differing social groups could be expected. In theory this policy blueprint is positive in providing economically encouraging methods to create an energy aware society. However, as associated results have not materialised from this method, results here indicate that increased emphasis of public as well as private methods may be useful. This means the GD and ECO score a '3' in this study (Fig. 1), as there is a moderate tackling of information and awareness barriers. Research here indicates that in the case with CERT, innovative partnerships across public and private boundaries, financed by a larger public and obligation fund (Table 1), in comparison to the GD and ECO provided increased levels of engagement with the public. Therefore, an emphasis on not limiting the types of delivery methods used, as CERT does, could provide a market focused on providing tailored solutions, to differing social groups. This success in uptake appears to show that the methods utilised in lead generation were effective, offering supporting results to the policy documentation, giving CERT a score of '4' (Fig. 1). It is also acknowledged here however, that to enable these innovative types of partnerships, CERT did have to input greater levels of public funding than within the GD framework. From an opposite perspective the apparent weak effectiveness in producing awareness increases on the ground means that CESP scores '2' in Fig. 1. Although successful in generating retrofit at scale within certain postcodes, following up retrofit work with comprehensive education is deemed to be required.

Furthermore, the fact that the EERS sector is in many ways a development of the traditional construction sector, means that a policy emphasis upon setting priorities which support market growth, investor risk limitation, and innovation encouragement are considered to be required to increase growth to provide retrofit at a significantly larger scale. Although it is considered that the GD attempted to create an EERS sector environment which demanded growth and innovation, there appeared to be issues that the GD required high growth rates in the short term. The costs impacting EERS sector stakeholders due to these expectations meant that the policy did not explicitly provide measures to assist businesses in this matter, even though the accreditation scheme aided cost reduction. This means the GD scores '2' in this study for hidden cost removal (Fig. 1). The impact of the hidden costs on these expanding businesses is also an issue for ECO, as although the brokerage platform is designed to remove transaction costs, uncertainty in the format has seemingly resulted in stalling from businesses to limit risk. ECO's performance therefore produces a score of '3' (Fig. 1) due to the provision of barrier removal by the brokerage, but without extensive associated results. This uncertainty of policy details was also considered a determinant of the success of CERT. Within policy documentation there is a provision for an environment whereby stability and certainty foster lower hidden costs, however due to

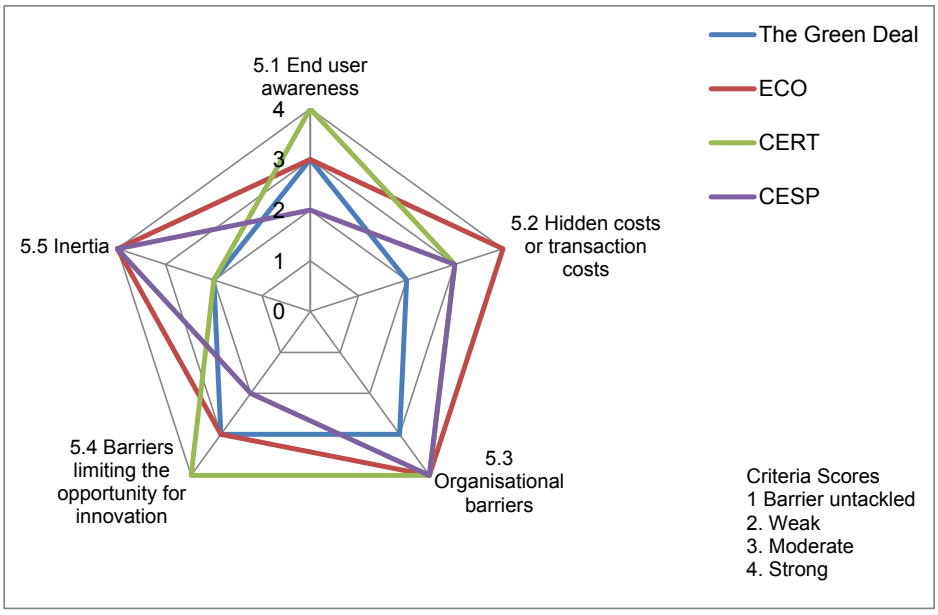

Fig. 1. Radar Chart detailing barrier removal capabilities of the GD, ECO, CERT and CESP.

policy changes and inter-business competition, significant results of hidden cost removal did not appear to materialise, resulting in a '3' score here (Fig. 1). CESP represents a case of utilising existing systems, and although operating at a smaller scale to the other policies considered here, it does characterise a method of limiting risk by working with present tools. Therefore, one method to create retrofit at scale would be to build on present supply chain configurations, as opposed to implementing an entire new paradigm. However, even with the use of tried and tested methods, CESP via its lack of certainty, caused delivery chains to encounter additional hidden costs to provide commercial risk aversion, causing an absence of associated results and therefore a score of '3' (Fig. 1).

For a business attempting to maximise profit from operating in a sector under the influence of a dynamic policy landscape, adopting the correct business structure is believed to be vital. Within the policies reviewed here, two central factors are considered important in the production of effective policy schemes. Firstly, to create a reputable delivery structure, accreditation schemes are required, such as within the GD and ECO. ECO therefore scores highly (4) on the radar graph (Fig. 1) for the removal of organisational barriers, due to the creation of an environment which fosters retrofit at volume through correct investment and supply chain organisation. The GD on the other hand scores '3' (Fig. 1), for the same reasoning, but the lack of associated results causes the lower score. Innovation is considered also to be a requirement needed to be encouraged via policy, to increase the ability of technological and techniques designed to tackle retrofit projects. This appeared to be particularly evident within the CERT system, which removed constraints to business practice, generating a score of '4' (Fig. 1). Lastly, to galvanise the efforts of business, a certain level of obligation needs to be introduced, to both public and private stakeholders, this could be to drive training schemes forward, or to increase investment in partnerships and technology research. Evidence reviewed here appears to show that CESP leaves the barrier of hidden costs hindering retrofit at scale un-tackled, and therefore scores '1' in this study.

Policy mechanisms to encourage investment and thus innovation growth, in terms of this study have been structured around the central issue of adaptation. To ensure effective innovations have maximum impact upon the UK housing stock, a flexible approach to differing products and processes is deemed to be required, ensuring that policy is driving the research and development within the sector. This flexibility in permitted measures also needs to be extended to the types of finance packages available for any particular retrofit scheme. Although the GD to an extent adopts this flexibility, attention is required to encourage more innovative delivery partnerships. This analysis shows that GD policy documentation addresses this, but due to present low numbers of retrofit projects the policy only scores '3' here due to a lack of connected results (Fig. 1). Similarly to the GD, ECO does have provisions to encourage investment and innovation, however in the limited areas where ECO is focused; according to evidence here UK housing stock heterogeneity has not been addressed. This results in a score of '3' here (Fig. 1). Although CERT was successful in structuring a market place where new working relationships were encouraged, for policy learning to occur and for a whole house retrofit focus to prevail, a compromise is considered to be required whereby an overreliance upon subsidy doesn't occur. As documented here, not only did CERT cost the government more to implement (Table 1), it also produced a false market, whereby natural market drivers and innovation was affected. Nevertheless, this approach produced innovative methods specifically designed for a certain type of house or development (ERA, 2011), scoring the policy '4' in this study. CESP on the other hand is considered to only weakly deal with the barrier, with subsidies limiting market drive to innovate resulting in a score of '2' (Fig. 1).

In producing policy mechanisms to ensure the continuous and sustainable supply of properties, the need to ensure members of the public are fully informed regarding policy benefits is believed important. From the policies considered here, the most effective mechanism is that of removing the involvement of end users all together, as CESP did. This provided a streamlining of the supply of retrofit measures, providing associated results, scoring CESP '4' in this review (Fig. 1). However, this method could not be rolled out nationally as it only applies to socially deprived households. ECO also achieves a score of '4' here (Fig. 1), linking the high volume of results with a delivery system taking the emphasis away from end users. For both the GD and CERT, without a policy which provides high levels of marketing, certainty in structure, appealing finance deals, and an addressing of end user behaviour, a high volume

supply of properties appears to not result. Overall therefore, the GD inadequately addresses the issue of generating an EERS sector which promotes the removal of inertia; its theoretical seamless delivery system is hindered by a low appeal loan system, meaning the barrier remains only weakly tackled, scoring the GD '2' (Fig. 1). Plus, CERT only weakly addresses the need to encourage a sustainable supply of properties for retrofit. Due to the apparent limited emphasis upon end user engagement and encouragement of the supply chain to produce new methods of property supply, the policy scores '2' here (Fig. 1).

Overall, this review of the varying policy schemes, in relation to barrier removal (Fig. 1), produced the following scores (Table 3) for each mechanism:

Table 3
Overall performance score for each policy.

Policy	Overall score	Rank
GD	13	4
ECO	18	1
CERT	17	2
CESP	15	3

This ranking of the policies, displays that schemes which have such characteristics as ECO and CERT harbour the greatest opportunity to remove barriers and promote EERS sector growth (Table 3). Mechanisms which incorporate the mandatory nature of obligation schemes, linked in with those schemes which provide space for innovative ideas to foster, in how to operate and also in what products to supply, are shown in this research to provide the most rewarding results. These results are not simply in terms of profit and volume of retrofit completed, but also the degree of EERS sector ability progress, and the level in which policies are prioritising the most vulnerable households. This is important to note, as volume of retrofit measures completed will increase with a rise in government financial assistance, as with CERT versus the GD for example, therefore it is important to disconnect the results here with simply the amount of money spent, and instead look at the level of progress made in terms of supply chain capabilities, effectiveness of carbon savings, and end user engagement.

7. Conclusion

Overall to achieve high participation, innovative instruments are required which capture the interest of both industry actors and end users. The evolving policy landscape discussed here shows certain barriers are being addressed by the differing policies. However, even these mechanisms which have produced significant carbon savings in places are still considered inadequate by many commentators. For instance, flexibility from policies to enable homeowners to choose to take retrofit project further to deeper levels has yet to occur. The standpoint of policies to focus on singular measures enables an increase in the level of properties able to be retrofitted, but it does neglect those households which wish to pursue greater carbon and energy savings.

The GD with its ambitious expectation of private industry generating its own leads and providing a growing diverse market did, in its intentions, encompass the needs of both private business and end users. However, due to the lack of obligation or regulation, and minimal government financial assistance, high levels of information provision and private finance did not materialise. This obligatory nature of policy is evident within the three other policies considered here, and although these schemes achieve a higher level of retrofit, the concept of enabling deeper retrofit projects via policy, with an understanding of how building physics operate and how differing measures interact with each other, are not prioritised. Therefore an emphasis on the long term impact of a retrofit project is required. This focus on linking property to occupants highlights the need to place as much importance on the EERS sector ability to install and provide quality retrofit as educating and increasing awareness and public knowledge.

This review of UK past and present policies, produces a timeline of impacts retrofit policy has had upon the EERS sector within the UK. In evaluating these policies, attention is clearly required in viewing how differing policy tools interact with and impact supply chains and end users from differing angles. Adopting this standpoint could enable a smooth customer journey to increase energy efficiency and enable a heightened level of awareness. To corroborate these results further primary research of on the ground sources regarding practitioner experience of the policy schemes could enable increased insight and enhanced indication as to where policy should be moving to.

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